

*HUMAN SENSITIVITY TO CONCURRENT SCHEDULES OF  
REINFORCEMENT: EFFECTS OF OBSERVING  
SCHEDULE-CORRELATED STIMULI*

GREGORY J. MADDEN AND MICHAEL PERONE

WEST VIRGINIA UNIVERSITY

The determinants of human sensitivity to concurrent variable-interval variable-interval schedules of reinforcement have been difficult to identify, in part because of procedural differences separating published experiments. This experiment investigated vigilance to stimuli correlated with concurrent schedules. Across phases, 3 college students were provided with either no schedule-correlated stimuli, an observing response that provided brief access to the stimuli, or a contingency that required the subject to identify the stimulus correlated with the source of each obtained reinforcer. Sensitivity, as quantified by the generalized matching equation, was low when no stimuli were available. When the stimuli were response contingent, 1 subject observed them, and her behavior became more sensitive to the distribution of reinforcers across the concurrent schedules. When the procedure required discrimination of the stimulus correlated with each reinforcer, the other 2 subjects also observed the stimuli, and their schedule sensitivity was increased as well. These results implicate procedural differences, rather than inherent behavioral differences, as the source of differences in sensitivity to schedules of reinforcement between humans and nonhumans.

*Key words:* concurrent schedules, matching, schedule sensitivity, observing response, variable-interval schedule, mouse click, college students

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Answering the question of how sensitive human behavior is to operant contingencies has not been easy. The prevailing strategy has been to compare the laboratory performances of humans with those of nonhuman animals under putatively similar schedules of reinforcement, with the animal performance regarded as the benchmark (Perone, Galizio, & Baron, 1988). Another strategy, with both human and animal subjects, has been to measure behavior change following manipulation of schedule parameters (Madden, Chase, & Joyce, 1998; Perone et al., 1988). Either way, the findings to date have been inconsistent (for reviews, see Bradshaw & Szabadi, 1988; Higgins & Morris, 1984; Horne & Lowe, 1993; Kollins, Newland, & Critchfield, 1997;

Lowe, 1979; Mazur, 1998; Perone et al., 1988; Pierce & Epling, 1983; Shull & Lawrence, 1998). Although some research suggests that human behavior is as sensitive to reinforcement as animal behavior, other research suggests that human behavior is much less sensitive. The differences between human and animal data have been common enough to lead some investigators to suggest that there are fundamental differences in the principles that govern human and animal behavior (e.g., Davey, 1988; Horne & Lowe, 1993; Lowe, 1979, 1983; Schwartz & Lacy, 1988; Wearden, 1988). Others investigators, however, have argued that important procedural variations between human and animal research may account for many of the behavioral differences, thus preserving hope that a common set of principles will eventually be found (e.g., Baron, Perone, & Galizio, 1991a, 1991b; Kollins et al., 1997; Perone et al., 1988; Pierce & Epling, 1991; Shull & Lawrence, 1991).

Concurrent schedules of reinforcement, in conjunction with Baum's (1974) generalized version of Herrnstein's (1961) matching equation, provide a well-established method for assessing sensitivity to changing contingencies of reinforcement in quantitative terms. According to the generalized matching equation,

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Address correspondence to Gregory J. Madden, Department of Psychology, University of Wisconsin-Eau Claire, Eau Claire, Wisconsin 54702 (E-mail: maddengj@uwec.edu).

$$(B_1/B_2) = k(R_1/R_2)^a, \quad (1)$$

where  $B_1$  and  $B_2$  are measures of the behavior allocated to the two concurrent schedules,  $R_1$  and  $R_2$  are the rates of reinforcement on the schedules,  $k$  is bias in the tendency to allocate behavior to one schedule or the other, and  $a$  is sensitivity to changes in the distribution of reinforcers across the schedules. So that least squares linear regression can be used to determine the values of the constants, the equation is commonly used in its logarithmic form:

$$\log(B_1/B_2) = a \log(R_1/R_2) + \log k, \quad (2)$$

where  $a$  is the slope and  $\log k$  is the intercept of the linear function relating the logs of the behavior and reinforcement ratios.

Of primary interest is the sensitivity parameter of the generalized matching equation. A value of one indicates that changes in the behavior ratios across the concurrent schedules are perfectly proportional to changes in the reinforcement ratios, a condition known as *ideal matching*. Values below one indicate that changes in behavior are less extreme than changes in reinforcement, a condition of reduced sensitivity known as *undermatching*. Values above one indicate that changes in behavior are more extreme than changes in reinforcement; this enhanced sensitivity to reinforcement is called *overmatching*.

According to a model proposed by Davison and Jenkins (1985), discriminative stimuli play a major role in sensitivity to concurrent schedules of reinforcement. In their model, the sensitivity parameter of Baum's (1974) generalized matching equation ( $a$ ) is replaced by a parameter ( $d_r$ ) that reflects the discriminability of the concurrently available schedules, ranging from one (no discriminability) to infinity (maximal discriminability):

$$(B_1/B_2) = k(d_r R_1 + R_2)/(d_r R_2 + R_1). \quad (3)$$

The remaining terms are the same as those in Equations 1 and 2. Assuming no bias (i.e.,  $k = 1$ ), Equation 3 states that behavior ratios across the concurrent schedules are determined by the reinforcement ratios only to the extent that the two sources of reinforcement are discriminated. As discriminability increases,  $d_r$  increases, and the equation predicts that behavior ratios should more closely match reinforcement ratios. Indeed, as  $d_r$  ap-

proaches infinity, Equation 3 becomes the equivalent of Equation 1 with  $a = 1.0$  (ideal matching). By comparison, as the sources of reinforcement become less discriminable,  $d_r$  approaches one, and Equation 3 predicts that behavior should be distributed more equally across the alternative schedules regardless of the reinforcement distribution (undermatching). In support of the model, research using Findley's (1958) changeover-key procedure with pigeons has shown that the discriminability parameter, and the degree of matching, could be raised by increasing the physical disparity between stimuli that signal the available schedules (Alsop & Davison, 1992; Miller, Saunders, & Bourland, 1980). More recently, the model has been extended to account for choice among three, instead of just two, alternative schedules (Davison & McCarthy, 1994).

The experimental literature on matching in humans also lends support to the view that sensitivity is enhanced by procedures that increase the discriminability of the concurrent schedules. In Bradshaw's laboratory (the one that has most consistently reported human sensitivity that approaches ideal matching) the procedures involve stimuli that bear an ordinal relation to the relative rate of reinforcement afforded by the schedules. For example, in Bradshaw, Szabadi, and Bevan's (1979) study, the leftmost lamp on the subject's response panel was illuminated when the leanest schedule was operative and each successive lamp to the right was illuminated as increasingly richer schedules became operative (Takahashi & Iwamoto, 1986, also used this arrangement in their demonstration of human matching). Stimuli bearing such a nonarbitrary relation to reinforcement may capitalize on an adult human subject's verbal and problem-solving skills and allow rapid development of discriminative control. Indeed, Bradshaw et al.'s 3 subjects overmatched ( $a = 1.20, 1.36, \text{ and } 1.38$ ). By comparison, when Horne and Lowe (1993) replicated Bradshaw's procedures without ordinal stimuli, sensitivity was poor, and 4 of 5 subjects undermatched severely ( $a = 0.53, 0.03, 0.04, 0.07, \text{ and } -0.06$ ).

The present experiment, like that of Horne and Lowe (1993), assessed the sensitivity of human behavior to concurrent schedules without ordinal stimuli. The schedules

were correlated with arbitrarily selected colors that bore no obvious relation to the scheduled rates of reinforcement. The question was whether sensitivity might be enhanced by manipulations that increased attention to these arbitrary stimuli and, in turn, the discriminability of the schedules they accompanied. In each condition, college students were exposed to several different pairs of variable-interval (VI) schedules, so that sensitivity (*a*) could be measured. In the first condition, schedule-correlated colors were unavailable. In the second condition, brief access to the colors was contingent on an observing response. In the third condition, the observing contingency was unchanged, but the monetary reinforcers were delivered only if the subject could correctly identify the color correlated with the source schedule. This manipulation was designed not only to increase observing rates but to *require* discrimination of the sources of reinforcement. According to Davison and Jenkins' (1985) model, this step should ensure a high degree of sensitivity to the concurrent schedules.

## METHOD

### *Subjects*

College students were recruited for voluntary participation by advertisements posted around West Virginia University and in the campus newspaper. Four women were selected from the pool of applicants because, according to their responses to a questionnaire, they were experimentally naive, needed money, and had no more than an introductory course in psychology. Before giving informed consent, each subject participated in a trial session to illustrate the basic procedure and to ensure that she could move a computer mouse comfortably and name the colors to be used as schedule-correlated stimuli. One subject withdrew after the second experimental condition, and her data will not be presented or discussed because she engaged in no observing behavior. The remaining subjects were 22 (Subject S1), 31 (S2), and 20 (S3) years old. They were paid a base rate of \$0.40 for each 20-min session, plus the monetary reinforcers obtained during the session. Earnings averaged \$4.18 per hour.

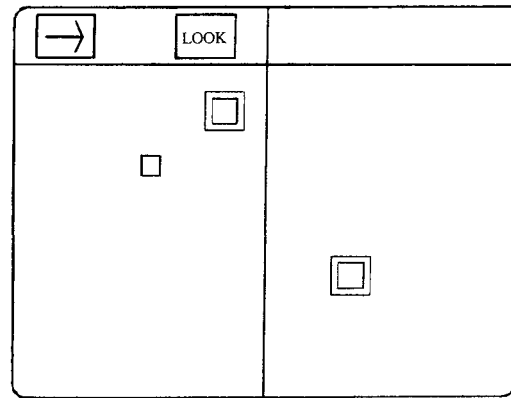


Fig. 1. Illustration of visual display. A separate hollow box moved independently within the boundaries on its side of the work area. Movement of the mouse cursor (which appears on left side of work area) was limited to one side until a changeover response was made by clicking the left mouse button while the mouse cursor was over the arrow button. Changeover responses relocated the mouse cursor and on-screen buttons to the other side of the work area. The "look" button initiated a 10-s period in which schedule-correlated stimuli were presented (see text for details). The latter button was not available during the no-stimuli condition.

### *Apparatus*

Each subject sat alone in a quiet room, at a table with a response console containing a 14-in. VGA color computer monitor, a computer mouse, and two push buttons. A black button, the "reinforcer collection" button, was mounted on the face of the console, 3 cm from the right edge. A red button was mounted on top of a small aluminum box connected to the left side of an arm of the console that projected 30 cm toward the left side of the subject. These buttons closed separate circuits when pressed with a force of approximately 1 N. The mouse was placed on a pad in front of the response panel. White noise was delivered through headphones to mask extraneous sounds. A microcomputer in an adjacent room was used to control the experimental events and record the data.

### *General Procedure*

Each subject came to the laboratory 5 days per week, and each day there were five 20-min sessions separated by brief rest periods.

*Response.* As shown in Figure 1, white frames divided the computer screen into two areas, defining the locations in which the subject could respond on two concurrently avail-

able VI schedules. The reinforced response was clicking the left button of the computer mouse while the mouse cursor (a 0.5-cm solid white square) was on a target (a 1-cm hollow white square) that moved about the response area at a rate of 1 cm per second. There was one target in each response area. Each target's movement was independent of the other, and directions were randomly changed every 2 s. When a target contacted the frame surrounding the response area, it changed direction, appearing to bounce off the frame. Because the subject had to track a moving target to make an effective response, the procedure encouraged the subject to watch the computer screen throughout the session. Feedback for effective responses was provided by "flashing" the target: The hollow box turned solid for 0.02 s.

*Switching between the schedules.* At the beginning of each session, the mouse cursor was placed in one of the two response areas at random. Responding on the moving target was limited to that area until a changeover response was made by moving the cursor to an on-screen changeover button and clicking the left mouse button twice. The changeover button was located directly above the currently chosen response area, and was inscribed with an arrow pointing in the direction of the next changeover (e.g., if the current response area was on the left, as in Figure 1, the arrow pointed to the right). Two clicks on the changeover button relocated the mouse cursor (and changeover button) and allowed the subject to use the mouse to track and click the target in the other response area. First, however, there was a 3-s changeover delay, during which the computer screen was blank except for the text "computer reconfiguring." The response areas, targets, and mouse cursor were not on display during the changeover delay, so the instrumental response was not available. Other behavior, such as clicking the mouse buttons, had no programmed consequences.

*Reinforcement.* When clicking the target fulfilled the reinforcement contingency programmed on that target, the target turned solid and remained so until the subject pressed the black button on the face of the console, or until 2 s elapsed. If the button was pressed in time, the screen was blank except for a message indicating that "Four cents has

been added to your earnings. Press left mouse button to continue." If the subject failed to press the button on the console, the message was "Too late. No money. Press the left mouse button to continue." In either case, after the subject clicked the left mouse button, the framed response areas, moving targets, and mouse cursor were restored. All schedule timers and the session clock were suspended during the reinforcer-delivery period (i.e., from the point at which the console button was pressed or the "too late" screen was presented, until the mouse button was clicked to clear the on-screen message).

*Eliminating extraneous behavior.* Throughout each session, the subject was required to hold down the red button on the left side of the console. Releasing the button initiated a 5-s timeout, during which the schedule timers and session clock were suspended and the screen was blank except for this message: "Illegal button release. You must hold down the red button at all times." If the red button was not pressed at the end of the 5 s, the timeout was restarted. The requirement to hold down the red button, in conjunction with the requirement to watch and track a moving target, was designed to occupy the subject's eyes and hands. The objective was to discourage the subject from leaving the apparatus or engaging in other behavior that might diminish the opportunity for schedule control to develop.

*Schedules.* Independent VI schedules were programmed on the two response areas. The sequence of 15 intervals comprising each schedule was generated using Fleshler and Hoffman's (1962) procedure. The mean VI values were 10 s, 26 s, 65 s, 164 s, and 410 s. The intermediate schedule, VI 65 s, was paired with each of the others to create reinforcer ratios, in logarithmic terms, ranging from  $-0.8$  to  $+0.8$ . The order of schedule presentation is shown in Table 1.

One goal of this experiment was to measure rates at which the subject observed stimuli correlated with the concurrent VI schedules. If each session had only a single pair of schedules (e.g., VI 10 s on the left and VI 65 s on the right), then the subject might observe the stimuli just once per session, because subsequent observations would always yield the same stimulus configuration. To encourage higher rates of observing, the sched-

Table 1

Values of the variable-interval schedules comprising the two pairs of concurrent schedules in each phase of each condition, along with the colors that could accompany the schedules and the number of sessions per phase. In the no-stimuli condition the frames of the two response areas were always white. In other conditions the white frames could be replaced by colored frames correlated with the schedules, contingent on an observing response. The two phases within each condition were conducted in the order shown for Subjects S1 and S2 (i.e., A then B); for S3, however, the phases were conducted in reverse order (B then A).

Condition	Phase	Sessions			Concurrent VI schedules and colors	
		S1	S2	S3	First pair	Second pair
No stimuli	A	11 <sup>a</sup>	15	21	65 (W), 10 (W)	65 (W), 410 (W)
	B	21	11	16	65 (W), 26 (W)	65 (W), 164 (W)
Observing	A	11	23	15	65 (R), 10 (B)	65 (R), 410 (Y)
	B	12		22	65 (R), 26 (M)	65 (R), 164 (G)
Naming	A	2	20	30	65 (R), 10 (LG)	65 (R), 410 (LB)
	B	2	27	22	65 (R), 26 (LR)	65 (R), 164 (C)
Observing (replication)	A	16 <sup>b</sup>	14	12	65 (R), 10 (B)	65 (R), 410 (Y)
	B	22 <sup>b</sup>	10	22	65 (R), 26 (M)	65 (R), 164 (G)
No stimuli (replication)	A	10 <sup>b</sup>	10	10	65 (W), 10 (W)	65 (W), 410 (W)
	B	10 <sup>b</sup>	10	10	65 (W), 26 (W)	65 (W), 164 (W)

*Note.* Color abbreviations: B = blue, C = cyan, G = green, LB = light blue, LG = light gray, LR = light red, M = magenta, R = red, Y = yellow, W = white.

<sup>a</sup> Sessions conducted after instructions about responding on both sides of the screen. The total number of sessions in Phase A was 39.

<sup>b</sup> Nonindependent concurrent schedules in these sessions.

ules and available stimuli had to be changed occasionally within each session. Thus, two pairs of VI schedules alternated unpredictably within each session. For example, sometimes a VI 10 s schedule would be paired with VI 65 s, and at other times VI 410 s would be paired with VI 65 s. In addition, the individual schedules comprising the pair would occasionally trade places. For example, sometimes VI 10 s would be on the left and VI 65 s on the right, but at other times within the same session, VI 65 s would be on the left and

VI 10 s on the right. A graphic illustration of these changes, for part of a session, is shown in Figure 2.

Once in operation, a single pair of schedules was continued for 40 s to 400 s before being replaced by the other pair of schedules. The two pairs alternated 3 to 11 times over the course of a session, until each had been in operation for 10 min. To ensure that position biases could be detected, each individual member of the pairs was assigned to the left and right response areas equally (i.e., 5 min per side per session).

As shown in Table 1, each experimental condition consisted of two phases, each involving a different pair of schedules. Estimates of sensitivity in each condition were based on reinforcer ratios derived from eight pairs of concurrent schedules. This is because each schedule in a pair was sometimes arranged on the right response area and sometimes on the left. Thus, each pair of schedules shown in Table 1 (e.g., VI 65 s and VI 10 s) produced two reinforcer ratios (e.g., in log terms, the ratio of left to right reinforcement rates was  $-0.8$  when VI 65 s was on the left and was  $+0.8$  when VI 10 s was on the left).

*Stability criteria.* Except as noted below, each

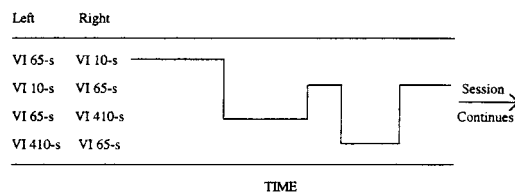


Fig. 2. Hypothetical sequence of programmed changes between concurrent VI VI schedules. Variable-interval schedules operative on the left and right sides of the work area of the computer screen are shown. Horizontal lines aligned with each set of concurrent schedules illustrate the time that the indicated concurrent schedule was operative before a programmed change to another concurrent schedule (i.e., a change initiated by the computer rather than a changeover response). See text for additional details.



phase continued for at least 10 sessions, and until behavior stabilized. Judgments about stability were based on relative response rates (i.e., response rates on the left divided by the sum of rates on the left and right) calculated for each pair of schedules, with separate consideration of the two possible spatial configurations of the individual VIs. For example, in the phase illustrated in Figure 2, there are two pairs of concurrent schedules (VI 10 s with VI 65 s and VI 410 s with VI 65 s), and each pair is presented in two ways (e.g., VI 10 s on the left and VI 65 s on the right, and vice versa), yielding a total of four schedule configurations. Relative rates were calculated for all four such configurations.

The stability criteria considered the most recent six sessions. For each relative rate, we calculated the difference between the mean of the first three sessions and last three sessions. The differences for three of the four relative rates had to be no more than 0.15. In addition, session-by-session graphs of the rates had to be free of trend, as judged by visual inspection. If the arithmetic criterion was not met after 20 sessions, the phase was ended as soon as visual inspection indicated the absence of trend. In the end, of all difference scores calculated to assess stability, 94% were less than 0.15 and 85% were less than 0.10.

### *Experimental Conditions*

The strategy was to assess sensitivity (*a*) in three experimental conditions that differed in terms of access to discriminative stimuli. Within each condition, the assessment was based on results from four pairs of concurrent schedules, two per phase, as summarized in Table 1.

*No stimuli.* In the first condition, schedule-correlated stimuli were unavailable. The frames defining the two response areas were always white, regardless of the schedule programmed on each area. These instructions were displayed on the computer screen before each session:

To earn money, put the mouse cursor in one of the hollow boxes on the screen and press the left mouse button. When you have made a successful response inside one of the hollow boxes, the box will briefly turn solid. You can move the mouse from one side of the screen to the other by positioning the mouse cursor

over the button at the top of the screen with the arrow on it, and pressing the left mouse button. When either of the hollow boxes turns to a solid box for longer than just an instant, you have earned money. To collect your money, press the black button on the console in front of you. You will have to press it quickly or you will lose the money you earned. You must hold down the red button to your left throughout the session. Releasing the button will start a 5-second delay during which you may not earn any money. It's up to you how frequently or infrequently you want to respond.

Before the first session the experimenter read the instructions aloud while pointing to the mouse and buttons at appropriate times. Questions were answered by referring the subject to the instructions or by saying, "You will figure that out by working on the task."

Because Subject S1 responded exclusively on one side of the screen during the first 15 sessions of Phase A, she was read the following supplemental instructions before Session 16 (but these instructions were not added to the on-screen display):

You can earn money by pressing the mouse button while the mouse cursor is over the left or right hollow box. It is up to you to decide which box to use at any given time. You are free to switch back-and-forth at any time during the session.

Subject S1's changeover rate increased immediately following these instructions, and the phase was continued until the stability criteria had been satisfied.

*Observing.* During the next condition, a second on-screen button, located next to the changeover button, was introduced to serve as an observing response. The word "look" was inscribed on the button (see Figure 1). When the subject used the mouse to click the button, schedule-correlated colors were presented for 10 s. That is, the frames defining the two response areas and the response target moving within each area were changed from white to colors correlated with the VI schedules. If, for example, a subject emitted an observing response while the VI 10-s schedule was operative on the left and the VI 65-s schedule was operative on the right, then the left frame and target would change from white to blue and the right frame and target would change to red, all for 10 s. Observing

responses during the 10-s stimulus periods had no programmed consequences and were not recorded. After the 10-s period elapsed, the frames and response targets changed back to white until the next observing response. As summarized in Table 1, each VI schedule was correlated with a unique color, and the same color-schedule correlations were used with all subjects.

The instructions displayed on the computer screen before each session included the following addendum, which appeared in red letters:

The "look" button at the top of the screen will allow you to look at the different colors on the sides of the screen for some time. It is completely up to you whether you want to "look" or not.

Once again, these instructions were read aloud to the subject before the first session of the condition.

During Phase A of the initial observing condition, Subject S1 developed a pattern of responding exclusively on the richer of the concurrently available schedules. To encourage some distribution of responses across the two alternatives, the independent concurrent schedules were replaced with nonindependent schedules arranged according to Stubbs and Pliskoff's (1969) procedure. A single VI schedule was programmed and reinforcers were assigned to the two response areas at probabilities that, on average, arranged the same interreinforcement intervals as the independent schedules. The nonindependent scheduling procedure was used with Subject S1 (and only S1) during the replications of the observing and no-stimuli conditions. Subject S1 was not instructed about this change in procedure.

*Naming the source of reinforcement.* The third condition continued to make schedule-correlated stimuli available via observing responses, although new colors were correlated with the schedules (with the exception of the VI 65-s schedule, which remained red). In addition, the subject was required to identify the stimulus correlated with the schedule from which each reinforcer was obtained. After the subject pressed the black button on the console to collect a reinforcer, three colored rectangles were arranged vertically on the screen with the message "Identify the col-

or from which you obtained the money." The three colors were the ones correlated with the VI schedules operative in the current phase, with the position of the correct color randomly assigned (recall that one member of each pair of concurrent schedules was always VI 65 s, so there were only three unique schedules in any given session; see Table 1). The subject chose a color by moving the mouse cursor over it and clicking the left mouse button. The chosen color was then surrounded by a white rectangle while the reinforcement message was presented or, in the event of an error, while the reinforcer was canceled and the message was "Incorrect choice. No money. Press the left mouse button to continue." No time limit was placed on selecting a color, but the schedule and session timers were suspended throughout this extension of the reinforcement period. No new instructions were added in this condition.

*Replications.* After the naming condition, the observing and no-stimuli conditions were replicated. Each phase of the observing replication was continued until stability was achieved. In the no-stimuli replication, however, each phase was continued for 10 sessions because that was sufficient to establish the disintegration of the control that had been achieved previously.

## RESULTS

Figure 3 shows the number of observing responses in each session in which response-contingent stimuli were available. In each condition, filled circles show data from Phase A (in which VI 65 s was paired with VI 10 s and VI 410 s) and unfilled circles show data from Phase B (in which VI 65 s was paired with VI 26 s and VI 164 s). In the initial observing condition, Subject S1 was the only one to produce the stimuli frequently. Because Subject S2 stopped observing altogether during the last 12 sessions of Phase A, we decided to conserve resources by omitting Phase B. In the naming condition, when the subjects were required to identify the source of each monetary reinforcer, all 3 subjects observed reliably. Subject S1, who had already acquired the observing response, was exposed to only four sessions of the naming condition to assess whether she could identify

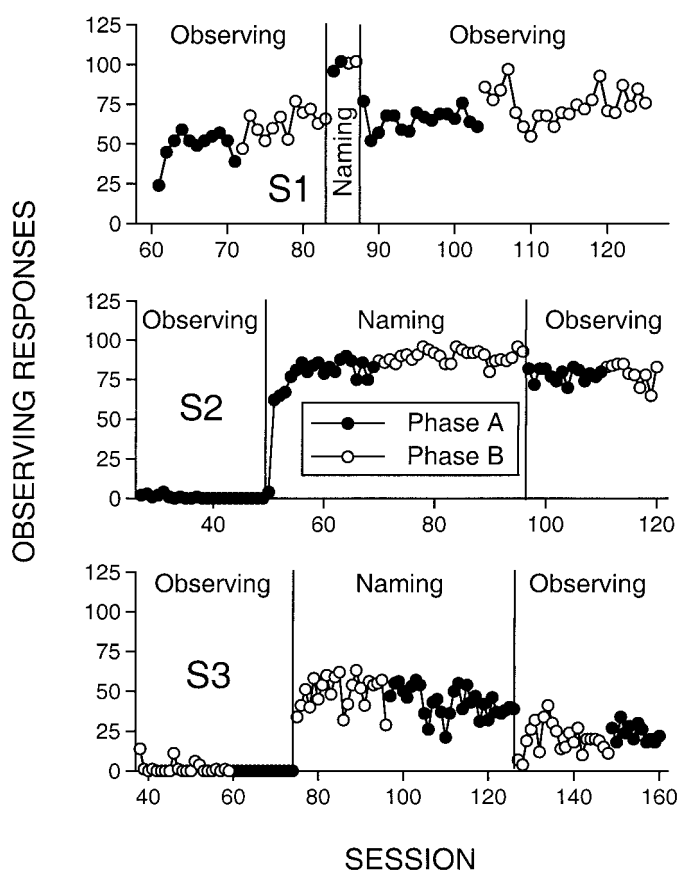


Fig. 3. Number of observing responses made per session in the observing and naming conditions (the no-stimuli condition is not represented because observing responses were unavailable).

the sources of reinforcement. The subject was correct in 99% of the cases. The other subjects also were accurate during the stable sessions. Subject S2 correctly identified the source of reinforcement in 99% of the cases, and Subject S3 did so in 96%. The last condition shown in Figure 3 is the observing replication. Even though the subjects were no longer required to name the source of reinforcement, observing behavior was maintained, albeit at lower rates for S3.

The Appendix shows, for the last six sessions of each phase, summary measures of the absolute response rates, time allocations, and reinforcer rates for every pair of schedules. Matching of behavior and reinforcement is assessed graphically in Figure 4, based on response allocation between the concurrent schedules, and Figure 5, based on time allocation. The regression lines fit the data adequately. Across subjects and condi-

tions, values of  $r^2$  averaged .82 ( $SD = .08$ ) for response allocation and .82 ( $SD = .10$ ) for time allocation. The mean squared error scores averaged 0.21 ( $SD = 0.14$ ) for response allocation and 0.15 ( $SD = 0.06$ ) for time allocation. As shown by the  $y$  intercept of the regression lines ( $\log k$ ), none of the subjects showed strong position bias, with values averaging  $-0.08$  ( $SD = 0.06$ ) for response allocation and  $-0.06$  ( $SD = 0.04$ ) for time allocation.

In Figure 4, changes in response ratios undermined the manipulation of reinforcer ratios when no stimuli accompanied the VI schedules. Although all subjects' sensitivity values (regression slope,  $a$ ) were positive, none exceeded 0.43 in either exposure to the no-stimuli condition (left panels). During the first exposure to the observing condition (middle panels), Subject S1 responded almost exclusively to the richer VI schedule; no



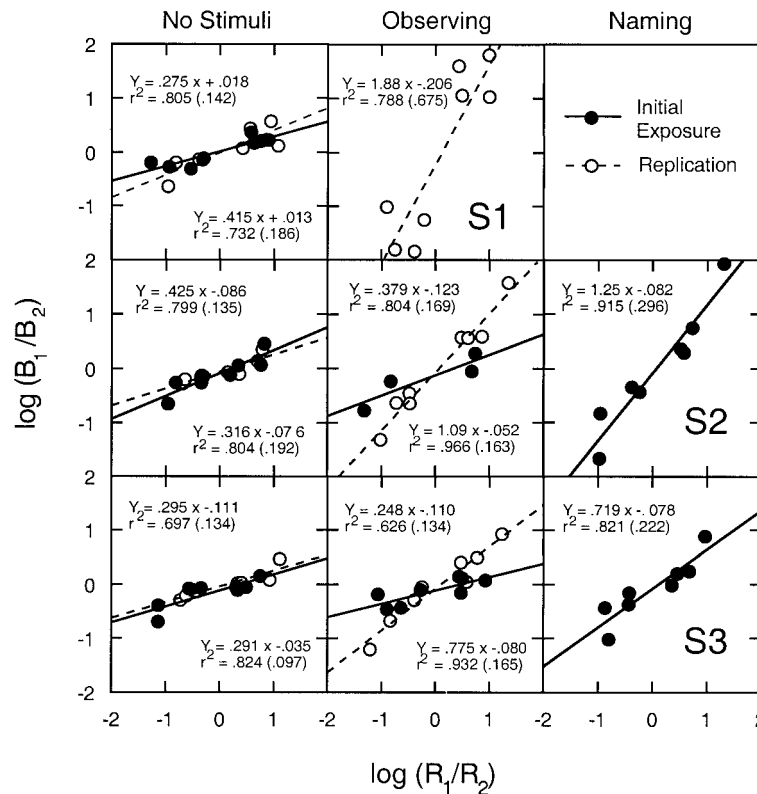


Fig. 4. Logarithmic response ratios plotted as a function of logarithmic obtained reinforcement ratios, based on data from the final six sessions of each condition. Initial exposure to each condition is shown by filled circles (and solid regression lines), and replications are shown as unfilled circles (and dashed regression lines). Linear equations are provided for each data set (initial exposures in the upper left, replications in the lower right). Pearson  $r^2$  and mean squared error values (in parentheses) are provided below each equation.

data from this exposure are shown in Figure 4 because some obtained reinforcement ratios contained a zero and therefore were undefined. The unfilled circles in S1's middle panel show results when the concurrent schedules were reprogrammed as nonindependent schedules. The subject overmatched ( $a = 1.88$ ). For Subjects S2 and S3, initial exposure to the observing condition did not change response allocations because these subjects failed to acquire the observing response at this point (only four filled circles are shown for S2 because, for reasons described above, she was exposed only to Phase A). When S2 and S3 were required to identify the source of reinforcement in the naming condition (right panels), and they did observe the schedule-correlated stimuli, their response ratios were more sensitive to the reinforcement ratios. The values of their sensitivity parameters increased by at least 0.47 to

values of 1.25 and 0.72, respectively. These values were sustained when the naming contingency was removed in the observing replication (middle panels).

Figure 5 shows the analysis of time allocation across the concurrent schedules. The basic results parallel those in Figure 4, with one noteworthy exception: In conditions in which response ratios overmatched reinforcer ratios, time ratios were moderated somewhat. In the naming condition and observing replication, Subject S2's response-ratio sensitivity values were 1.25 and 1.09, respectively (see Figure 4), but the corresponding values for time allocation were 0.96 and 0.95 (Figure 5). Subject S1 provides a more extreme example. During the observing condition, her response-ratio sensitivity was 1.88 (Figure 4), but her time allocation sensitivity was 1.26 (Figure 5). This reduction occurred because she tended to emit a single response on the

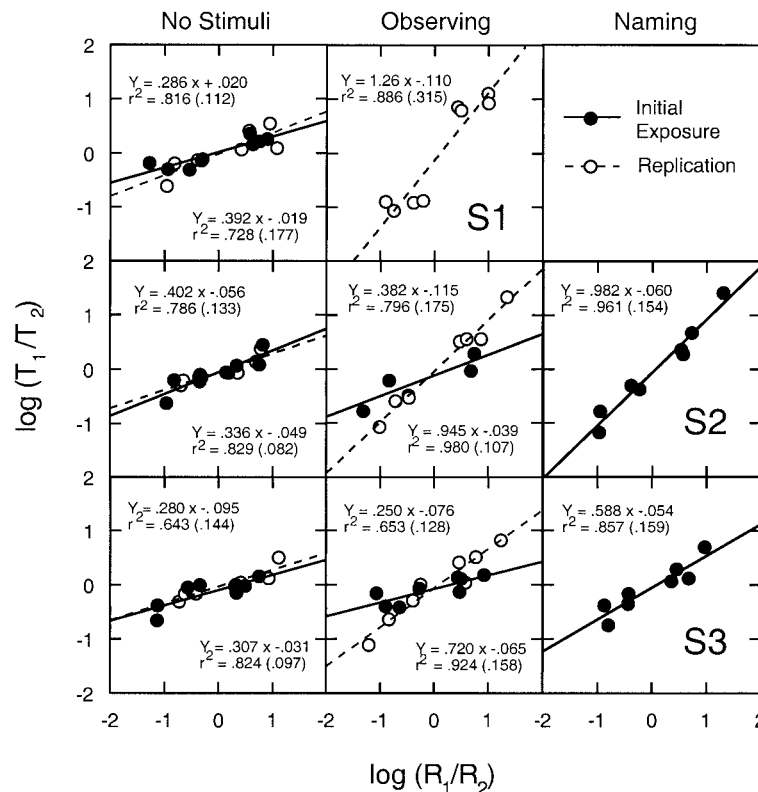


Fig. 5. Logarithmic time-allocation ratios plotted as a function of logarithmic obtained reinforcement ratios. Format follows that of Figure 4.

leaner of the two schedules before switching back to the richer one. Because the subject took time to relocate the mouse cursor over the changeover button after almost every single response on the leaner schedule, the time spent on each response on that schedule was considerably greater than the time needed for any one response (of many) on the richer schedule.

## DISCUSSION

Human sensitivity to concurrent VI VI schedules of reinforcement was improved when subjects observed schedule-correlated stimuli. When such stimuli were unavailable, changes in behavior across schedule alternatives undermatched experimental manipulation of reinforcement ratios (i.e., behavior was relatively insensitive to reinforcement). When subjects were given the opportunity to observe schedule-correlated stimuli, 1 subject did and 2 did not. The subject who acquired

the observing response shifted from undermatching to overmatching (i.e., hypersensitivity), whereas those who did not observe showed no change in sensitivity. When subjects were required to correctly identify the source of each obtained reinforcer (or forfeit the money earned), observing response rates and sensitivity parameter values increased for subjects who had previously been insensitive to changes in concurrent-schedule parameters. When subjects were no longer required to identify the source of each reinforcer, observing was maintained and sensitivity parameter values remained high. However, when access to schedule-correlated stimuli was removed, sensitivity parameter values dramatically decreased.

Consistent with data reported by Horne and Lowe (1993), our findings suggest that schedule-correlated stimuli are critical in the development of human sensitivity to concurrent schedules of reinforcement (see also Takahashi & Iwamoto, 1986). When these

stimuli were either unavailable or unobserved, extreme undermatching predominated, but when they were available and observed, response and time allocations more closely matched obtained reinforcement ratios.

In animal experiments, the stimuli that accompany the reinforcement schedules are highly salient (e.g., they may be among the few sources of illumination in the operant chamber), and observing these stimuli may be virtually unavoidable (e.g., pigeons presumably observe these stimuli each time they peck a distinctively colored key or a key in a particular location). Under these conditions, relative response rates approximately match relative rates of reinforcement, and behavior is highly sensitive to changing concurrent schedules of reinforcement (e.g., Davison & McCarthy, 1988; deVilliers, 1977). When experimenters arrange identical schedule-correlated stimuli across the concurrent schedules (in much the same way that we did in our no-stimuli conditions), animal behavior is considerably less sensitive to changing schedule contingencies (Alsop & Davison, 1991; Miller et al., 1980), an outcome that is consistent with our findings.

In experiments that have examined human sensitivity to concurrent schedules of reinforcement, schedule-correlated stimuli are freely available but they frequently lack the salience they enjoy in the animal operant chamber. Unlike animals, human subjects usually can emit responses and collect reinforcers without looking at the stimuli. The rate at which human subjects actually do look at schedule-correlated stimuli is unmeasured and, therefore, unknown. Reports that human subjects frequently assume a sleeping posture or fall asleep during operant experiments (e.g., Buskist, Newland, & Sherburne, 1991; Matthews, Shimoff, Catania, & Sagvolden, 1977; Shimoff, Catania, & Matthews, 1981), and our finding that only 1 subject observed schedule-correlated stimuli when not required to do so, suggest that the usual rate of observing may be low. Failure to observe schedule-correlated stimuli may undermine discrimination between the different sources of reinforcement in concurrent-schedule procedures, thereby resulting in insensitivity (e.g., Alsop & Davison, 1991; Davison & Jenkins, 1985).

If observing schedule-correlated stimuli plays an important role in matching, and if we assume that humans typically do not observe, then how can empirical reports of human matching be understood in light of our findings? An analysis of the procedures used in those studies that report success in producing human matching suggests that all the procedures increase either the discriminability or the salience of schedule-correlated stimuli (when compared with studies in which human behavior is insensitive to concurrent schedules of reinforcement). The majority of these studies were conducted by Bradshaw and colleagues (e.g., Bradshaw, Szabadi, & Bevan, 1976, 1979; Bradshaw, Szabadi, Bevan, & Ruddle, 1979; Ruddle, Bradshaw, Szabadi, & Bevan, 1979) and, as discussed earlier, their practice was to arrange stimuli bearing an ordinal relation to the reinforcement rates afforded by the concurrent schedules (Takahashi & Iwamoto, 1986, also demonstrated matching in humans with ordinally arranged stimuli). Horne and Lowe (1993) demonstrated that without this stimulus arrangement, humans were insensitive to changing concurrent schedules.

If studies using ordinal stimuli are removed from the pool of experiments that have demonstrated human matching, then three studies remain: Schroeder and Holland (1969), Baum (1975), and Buskist and Miller (1981). In each of these experiments, reinforcement was contingent on the subject's continuous attention to schedule-correlated stimuli to detect available reinforcers, a procedure frequently referred to as a "vigilance task." Schroeder and Holland's subjects monitored two sides of a display panel to detect and report intermittent pointer deflections paired with money. Baum's subjects monitored a screen bathed in schedule-correlated colors so they could detect occasional incoming "missiles" that functioned as reinforcers. Buskist and Miller's subjects monitored the status of two vending machine doors (open or closed) in their attempts to obtain food reinforcers. Our findings join those of these experiments in suggesting that observing schedule-correlated stimuli is an important component of human sensitivity to concurrent schedules of reinforcement.

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## APPENDIX

Response rate, time allocation, and obtained reinforcement rate on the left and right response areas in each phase of each condition. The 20-min sessions within each phase incorporated four distinguishable pairs of variable-interval schedules, identified here by the mean scheduled interreinforcement interval (in seconds). Results are expressed as means ( $M$ ) and standard deviations ( $SD$ ) over the last six sessions of each phase.

Condition	Statistic	Phase A						Phase B									
		VI 10 VI 65	VI 65 VI 10	VI 410 VI 65	VI 410 VI 65	Left	Right	VI 26 VI 65	VI 65 VI 26	VI 164 VI 65	VI 164 VI 65	Left	Right				
Subject S1: Responses per session																	
No stimuli	M	613.8	365.2	339.2	633.7	386.0	597.5	596.7	404.0	743.8	318.8	347.3	699.8	454.8	587.3	658.5	404.7
	SD	136.0	130.8	151.9	176.1	82.1	79.3	154.0	136.3	182.8	174.1	149.3	171.0	97.7	105.0	255.3	259.3
Observing	M	972.8	3.0	1.7	946.8	47.2	833.3	806.7	65.8	989.8	1.7	1.0	989.5	77.5	845.8	805.0	127.5
	SD	20.5	2.2	1.7	12.6	53.0	59.0	105.9	80.3	48.3	2.4	1.5	41.7	86.5	100.5	77.0	85.2
Naming	M	736.5	50.0	0.5	704.5	35.0	848.0	677.0	201.5	759.0	1.5	92.0	719.5	347.0	444.5	609.0	160.0
	SD	30.5	42.0	0.5	16.5	35.0	23.0	187.0	199.5	42.0	0.5	92.0	80.5	189.0	176.5	167.0	154.0
Observing	M	785.3	12.2	12.0	753.0	70.3	715.5	727.7	67.0	776.5	19.5	11.3	774.7	39.8	715.0	717.8	62.5
	SD	67.3	5.5	4.9	63.4	56.9	110.1	96.1	48.0	51.4	6.7	4.1	57.6	44.1	42.7	57.7	52.7
No stimuli	M	737.7	195.5	172.0	750.2	349.8	545.3	510.7	391.2	723.0	261.2	419.2	571.7	414.3	557.0	538.2	448.7
	SD	91.6	88.4	94.1	103.3	70.5	79.9	75.4	71.9	137.0	110.7	193.6	204.0	223.8	241.4	91.8	130.3
Subject S1: Time allocation (s) per session																	
No stimuli	M	191.7	103.9	99.6	198.0	115.6	177.0	174.0	118.9	206.3	89.5	97.7	198.4	127.9	164.5	183.2	110.8
	SD	37.7	36.8	48.0	48.7	24.7	23.8	42.4	41.4	48.7	48.0	41.4	43.0	24.2	25.6	70.6	70.0
Observing	M	295.2	3.2	2.9	294.9	14.5	283.9	271.9	25.8	295.9	2.2	2.4	296.0	27.3	269.2	254.5	41.6
	SD	3.3	2.2	2.5	4.4	15.2	16.0	32.4	31.1	3.2	1.9	3.2	5.0	26.3	28.2	25.8	24.5
Naming	M	277.5	19.2	2.2	297.0	12.2	285.7	233.9	61.2	292.0	4.7	35.5	260.7	125.4	167.2	231.6	63.5
	SD	13.7	12.3	2.2	3.2	10.0	9.7	61.4	58.4	3.3	2.7	32.8	34.9	57.9	56.4	62.5	59.5
Observing	M	262.8	20.7	22.2	259.6	32.9	257.9	261.6	30.8	237.7	33.4	29.9	243.3	32.8	246.6	240.6	38.3
	SD	6.5	3.4	4.7	9.7	22.3	24.5	19.6	17.0	10.5	5.6	5.5	10.2	11.4	10.6	15.5	15.5
No stimuli	M	225.2	64.1	57.4	231.3	109.6	169.1	155.0	124.0	207.5	80.7	121.0	166.9	121.4	164.1	153.5	132.1
	SD	22.8	23.3	27.4	30.4	21.5	22.6	15.6	16.8	34.5	30.2	52.1	52.7	60.8	61.2	31.1	31.9
Subject S1: Obtained reinforcers per session																	
No stimuli	M	18.7	2.3	2.0	17.3	0.2	3.2	4.3	1.0	8.3	2.2	2.5	8.7	1.7	3.3	4.8	0.8
	SD	5.6	2.0	0.8	2.8	0.4	2.0	1.7	0.8	4.4	1.8	1.1	3.8	1.4	0.7	2.5	1.1
Observing	M	25.5	0.7	0.3	27.2	0.2	4.2	5.0	0.0	10.2	0.0	0.5	11.3	0.3	5.0	3.8	1.0
	SD	2.7	0.7	0.5	2.2	0.4	0.9	3.3	0.0	3.6	0.0	0.8	0.9	0.5	2.2	1.7	0.8
Naming	M	24.0	1.0	0.5	26.5	0.0	2.5	5.5	0.0	10.5	0.5	1.0	10.5	2.0	4.0	3.5	1.5
	SD	5.0	0.0	0.5	1.5	0.0	0.5	3.5	0.0	0.5	0.5	1.0	2.5	0.0	0.0	2.5	1.5
Observing	M	19.5	2.0	3.3	18.7	0.7	5.3	3.3	0.3	7.2	2.7	3.7	8.8	2.5	4.0	3.7	1.2
	SD	2.8	0.6	1.8	3.3	0.7	1.8	0.7	0.5	2.5	0.7	1.7	2.9	0.8	1.8	1.8	0.9
No stimuli	M	23.7	2.7	2.3	21.2	0.7	4.3	4.0	0.3	9.2	2.5	3.8	8.0	1.8	4.5	3.5	1.3
	SD	2.4	1.1	1.4	4.7	0.5	1.6	1.5	0.5	3.0	1.0	2.5	3.5	1.6	1.9	1.9	1.2

APPENDIX  
(Continued)

Condition	Statistic	Phase A						Phase B									
		VI 10 VI 65		VI 65 VI 10		VI 410 VI 65		VI 65 VI 410		VI 26 VI 65		VI 65 VI 26		VI 164 VI 65		VI 65 VI 164	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Subject S2: Responses per session																	
No stimuli	M	504.7	174.8	119.2	536.0	206.0	374.8	323.8	277.2	324.7	286.5	209.8	383.0	230.2	308.5	233.5	305.5
	SD	76.3	42.4	54.3	102.8	34.8	70.32	52.4	35.0	40.0	38.7	45.6	83.8	18.4	26.7	19.3	45.4
Observing	M	605.3	313.3	131.7	777.3	321.5	547.5	412.3	460.3								
	SD	66.6	46.3	68.8	77.9	73.5	102.8	95.4	60.7								
Naming	M	697.3	8.2	15.3	717.5	97.0	634.5	654.7	115.5	487.5	243.5	237.0	517.0	208.5	565.3	506.5	220.0
	SD	51.1	4.0	7.9	54.3	54.5	64.8	126.6	73.1	43.1	54.9	58.9	54.5	56.5	62.8	20.5	68.0
Observing	M	779.8	20.5	34.3	717.2	149.7	646.8	622.2	157.7	590.7	156.2	128.2	561.5	168.7	485.0	484.7	132.5
	SD	37.6	12.3	17.8	49.6	62.5	60.8	54.3	41.1	101.0	55.6	36.0	76.0	71.9	116.8	130.2	64.8
No stimuli	M	639.2	283.8	318.5	604.0	352.3	558.0	528.3	388.2	407.2	509.8	365.7	509.0	369.0	535.3	425.2	490.7
	SD	170.6	206.1	152.7	166.2	120.5	118.9	94.7	91.4	90.1	82.7	38.4	42.4	47.3	56.4	46.3	45.5
Subject S2: Time allocation (s) per session																	
No stimuli	M	211.8	75.3	54.6	230.1	104.6	164.5	146.6	120.1	144.6	124.3	99.1	166.2	113.9	143.4	118.9	138.8
	SD	20.9	18.9	22.4	25.3	18.2	19.4	15.7	13.0	16.2	10.3	14.6	19.0	10.9	11.5	7.2	11.3
Observing	M	191.2	98.3	41.5	250.3	105.0	170.0	133.2	144.1								
	SD	16.5	15.0	20.8	23.1	18.0	19.8	18.3	18.3								
Naming	M	282.2	10.9	18.2	270.2	40.7	248.2	237.6	50.0	185.5	96.8	94.4	187.9	84.7	196.9	197.1	85.6
	SD	5.6	3.9	6.7	9.2	22.1	28.8	37.4	30.0	17.2	18.8	17.9	21.8	20.0	21.4	30.2	25.1
Observing	M	281.0	13.2	22.8	266.7	58.6	231.0	225.8	62.9	218.6	68.0	64.6	219.7	70.8	213.8	225.5	62.3
	SD	7.0	5.1	9.0	12.3	21.4	21.3	18.3	16.6	24.7	21.5	10.4	12.4	26.5	29.0	32.8	28.9
No stimuli	M	203.7	85.4	95.9	190.2	107.2	173.0	162.3	118.7	129.9	150.0	115.3	161.5	116.0	160.5	129.5	147.3
	SD	55.7	54.7	43.7	45.2	30.2	29.8	21.5	21.8	22.4	23.0	7.7	8.7	12.3	11.8	11.6	13.9
Subject S2: Obtained reinforcers per session																	
No stimuli	M	20.0	3.0	2.3	21.3	0.7	4.3	3.8	0.7	9.8	4.5	3.3	7.3	1.8	4.0	3.3	2.2
	SD	1.9	1.5	1.1	4.3	0.5	1.5	1.5	0.7	1.1	2.4	1.5	1.1	0.7	0.8	2.1	1.1
Observing	M	18.3	3.3	1.2	23.8	0.7	4.5	3.2	0.7								
	SD	2.9	0.9	1.1	2.8	0.9	1.4	2.2	0.7								
Naming	M	27.0	1.3	2.5	23.3	0.5	4.5	4.5	0.8	9.3	2.5	3.7	8.8	1.8	3.2	3.8	1.2
	SD	3.2	0.5	1.0	2.1	0.8	2.3	2.6	0.9	0.7	1.3	1.1	1.8	1.1	1.1	2.0	1.1
Observing	M	26.0	1.2	2.2	22.2	0.8	4.3	3.7	0.5	8.5	2.8	3.5	10.3	1.5	4.5	3.3	0.8
	SD	1.8	0.9	0.7	2.3	0.9	1.1	1.6	0.5	3.5	1.1	1.3	3.5	1.3	1.4	1.5	0.7
No stimuli	M	17.2	2.8	3.0	14.7	0.8	3.7	4.2	0.8	7.7	3.3	3.7	7.5	1.8	4.2	3.0	2.2
	SD	8.2	2.2	1.8	6.3	1.2	1.4	2.7	0.7	2.2	1.5	2.4	1.5	0.7	2.0	1.3	1.1

APPENDIX  
(Continued)

Condition	Statistic	Phase A						Phase B									
		VI 10 VI 65		VI 410 VI 65		VI 65 VI 410		VI 26 VI 65		VI 65 VI 26		VI 164 VI 65		VI 65 VI 164			
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right		
Subject S3: Responses per session																	
No stimuli	M	176.7	123.8	53.7	263.0	98.7	241.7	145.3	183.2	103.5	116.5	107.0	124.0	117.5	139.2	107.5	121.5
	SD	87.9	82.9	51.1	40.5	60.9	76.2	76.1	71.6	80.9	90.7	60.4	154.8	47.0	119.0	81.8	101.6
Observing	M	139.5	116.2	60.5	175.5	99.3	152.2	101.2	144.3	155.5	121.5	126.5	161.0	77.0	209.2	167.7	119.0
	SD	45.3	86.0	55.3	60.0	25.6	53.6	53.0	51.7	62.5	50.3	68.0	70.1	64.1	83.6	53.9	56.9
Naming	M	331.7	43.7	29.3	305.5	49.7	135.0	124.3	71.0	205.3	129.3	101.3	236.7	118.2	167.8	151.0	154.7
	SD	72.1	7.3	10.0	51.4	26.2	44.9	59.7	32.0	27.2	38.2	38.2	49.0	35.3	36.2	37.3	21.4
Observing	M	531.8	62.3	34.2	543.7	93.0	433.5	398.3	128.0	384.5	151.3	191.8	371.8	262.7	294.2	283.0	252.3
	SD	69.3	67.2	19.5	61.9	61.5	78.1	58.4	56.8	48.9	54.7	46.6	68.2	51.6	42.3	96.8	49.4
No stimuli	M	342.8	117.5	157.3	309.2	162.0	260.5	240.5	198.5	256.5	243.5	220.5	294.3	231.2	294.5	276.2	257.7
	SD	78.1	80.3	61.7	56.2	57.5	61.1	87.2	103.7	60.5	53.2	85.9	64.5	59.8	65.8	64.5	55.6
Subject S3: Time allocation (s) per session																	
No stimuli	M	174.6	122.6	54.1	244.9	86.7	206.9	122.7	170.9	130.8	137.1	133.8	134.3	127.2	141.3	129.9	138.1
	SD	60.6	61.9	43.7	44.4	57.1	59.6	60.7	62.0	15.3	18.4	20.6	21.4	20.1	19.4	20.1	16.4
Observing	M	179.3	118.7	85.2	213.0	120.4	171.6	123.7	167.2	165.6	127.8	134.1	155.8	81.1	212.2	167.0	120.5
	SD	86.0	84.2	82.4	83.3	37.0	38.4	59.0	60.9	55.1	54.8	62.5	62.4	63.0	67.4	57.1	49.9
Naming	M	235.7	46.9	43.5	241.0	85.3	204.6	164.8	124.7	185.2	95.4	87.8	195.8	115.0	166.9	151.1	130.5
	SD	16.0	13.7	12.9	16.1	20.5	19.6	59.9	60.9	32.4	28.0	20.8	24.9	29.4	31.1	10.1	8.2
Observing	M	254.5	38.0	21.1	270.1	54.8	234.9	221.8	68.2	203.3	78.1	95.6	186.0	147.9	146.5	150.5	136.7
	SD	25.9	28.6	10.9	16.3	27.5	32.4	21.2	19.9	10.4	13.0	17.9	18.8	20.7	23.2	38.3	40.4
No stimuli	M	221.8	70.2	95.9	195.5	115.0	166.4	161.4	123.7	141.9	141.7	116.9	169.7	124.1	159.7	146.8	134.8
	SD	36.0	34.2	17.0	19.2	20.5	23.9	35.4	32.3	32.4	31.5	42.3	45.6	19.5	21.5	31.0	27.3
Subject S3: Obtained reinforcers per session																	
No stimuli	M	14.2	2.5	1.5	20.5	0.3	4.5	2.2	1.0	8.0	4.0	3.5	7.7	1.0	3.7	4.7	1.5
	SD	5.2	1.3	1.8	6.3	0.5	2.2	1.2	0.6	2.3	1.3	1.6	1.4	0.8	1.7	1.1	1.3
Observing	M	15.7	1.8	2.3	18.3	0.3	3.8	2.0	0.7	8.0	2.5	3.5	6.5	1.0	4.3	3.7	1.3
	SD	8.1	2.0	2.4	7.7	0.5	1.7	1.2	0.7	4.1	1.9	1.6	4.0	1.2	2.8	1.8	1.1
Naming	M	22.0	2.3	3.2	19.7	0.5	3.7	3.2	0.7	8.2	2.8	3.7	10.0	1.5	4.0	3.8	1.7
	SD	3.8	1.4	0.9	3.6	0.5	1.5	1.7	0.7	2.9	1.7	0.9	1.8	1.3	1.8	1.2	0.9
Observing	M	23.0	1.3	1.5	24.0	0.7	4.5	4.0	0.7	9.8	3.3	3.5	8.5	2.2	3.8	3.8	1.0
	SD	3.3	0.7	1.3	1.9	0.7	1.5	1.3	0.9	1.8	0.9	1.6	3.4	1.2	1.8	2.1	1.0
No stimuli	M	19.7	1.5	3.2	17.0	1.0	4.2	2.8	0.3	7.2	3.3	3.3	8.7	1.5	4.7	3.8	1.5
	SD	3.8	1.3	1.2	1.2	0.8	2.0	1.8	0.5	3.4	1.2	1.8	2.2	1.3	2.1	1.1	1.0